STOCK ASSESSMENT OF PACIFIC MACKEREL (*Scomber japonicus*) WITH RECOMMENDATIONS FOR THE 2004-2005 MANAGEMENT SEASON

EXECUTIVE SUMMARY

by

Kevin T. Hill and Paul R. Crone
NOAA Fisheries
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla, California 92037

Submitted to

Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 200
Portland, Oregon 97220-1384

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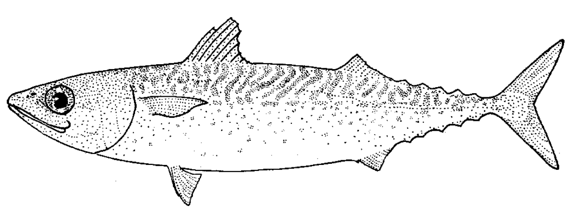

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INTRODUCTION

The following summarizes stock assessment results and harvest guideline (HG) recommendations for Pacific mackerel (*Scomber japonicus*) developed for the Pacific Fishery Management Council's (PFMC) management season of July 1, 2004 to June 30, 2005. This summary will also be included in the PFMC's Stock Assessment and Fishery Evaluation (SAFE) report for coastal pelagic species (CPS), and will be distributed prior to the June 2004 PFMC meeting. A comprehensive stock assessment report is concurrently being developed for the PFMC's first formal stock assessment review (STAR) scheduled for June 21-25, 2004.

SUMMARY OF THE 2003-2004 FISHING SEASON

The coast-wide harvest of Pacific mackerel decreased 35% in calendar year 2003 (Table 1, Figure 1). The directed fisheries off California and northern Baja California (Ensenada, Mexico) had a combined yield of 8,341 mt, compared to 12,778 mt in 2002. California's directed fishery for calendar year 2003 landed 5,185 mt – an increase of about 14% from the 2002 yield. The Ensenada fishery experienced a 65% decrease in yield, from 7,963 mt in 2002 to 2,815 mt in 2003 (Celia Eva Cotero, INP-Ensenada, pers. comm.). The RecFIN estimate of recreational harvest was 341 mt in 2003, up from 279 mt in 2002.

The U.S. commercial fishery was provided a 10,652 mt HG for the 2003-2004 (July-June) season, based on a July 1, 2003 biomass forecast of 68,924 mt (Hill et al. 2003). Through the PFMC management process, it was determined that in order to stay within the HG, there would be an initial directed fishery of 7,500 mt, with 3,152 mt set aside for incidental catch in other CPS fisheries. The 2003-2004 season has progressed slowly, with only 5,545 mt of the directed HG allocation being landed from July 2003 through March 2004. The fishery is projected to land a total of 5,735 mt through the end of June 2004, so will likely remain open through June 30, 2004.

Anecdotal observations from the field have attributed the reduced harvest from 2003-2004 to limited availability, rather than due to market conditions and/or redirected effort. Similar reasons have been postulated for the Ensenada fishery as well (Celia Eva Cotero, INP Ensenada, personal communication), which typically harvests larger yields when the fish are available. However, given the diversity of the species targeted by the CPS fleet at large over the years, it has been problematic objectively determining the influential factors that lead to reductions in harvest in the Pacific mackerel fishery. Finally, management-related information regarding this species' stock structure generally supported by the scientific community follow: (1) historically, mackerel spawning activity has been centered off the central and northern Baja California coast; (2) only limited data exist regarding mackerel abundance south of Ensenada; (3) mackerel have been present as incidental catch in whiting and salmon fisheries off Oregon and Washington since 1992; (4) during El Niño events, mackerel catches have been observed to increase in more northern (off Oregon and Washington) waters; and (5) the presence of older (say ages $3) and larger mackerel in this northern region, coupled with the relative paucity of these older age groups in the southern California landings, does generally support the expanding/contracting 'single-stock' hypothesis currently in place.

ASSESSMENT METHODS

Model

A modified virtual population analysis (VPA) model ('ADEPT,' Jacobson 1993), based on Gavaris' (1988) ADAPT procedure, was used to estimate biomass of Pacific mackerel. The ADEPT model has been used to assess Pacific mackerel for the past eleven years and is described in detail in Jacobson (1993), Jacobson et al. (1994), and Hill et al. (1999a,b). Conventional VPAs back-calculate age-structured abundance utilizing catch-at-age and weight-at-age data, as well as assumptions regarding both age-specific natural mortality in each year of the time series and fishing mortality (F) estimates for the most recent year (referred to as 'terminal F'). The ADEPT model improves upon a conventional VPA by evaluating terminal F and other parameters to obtain the best statistical fit between VPA output and survey indices of relative abundance. The crux of the statistical procedure lies in the model's ability to estimate terminal F based upon the survey indices, using them to adjust the conventional VPA output.

The ADEPT model uses a standard suite of subroutines to estimate parameters in a VPA model, based on a slightly modified simplex algorithm and subroutine from Press et al. (1990). The standard program for parameter estimation is similar to that described by Mittertreiner and Schnute (1985). The ADEPT approach is based on the estimation method of maximum likelihood. Parameters are estimated by minimizing an objective function, which in the case of ADEPT, is the negative log-likelihood of the data, given the model and parameter estimates (rather than the equivalent sums of squares used by Gavaris 1988). Two types of parameters are estimated in the ADEPT model: observation parameters (survey-based q's and exponents) and terminal F parameters. Observation parameters are used to interpret index data, which are used in turn to estimate terminal F values. Terminal F parameters are highly influential for estimating population biomass for recent years. Natural mortality was assumed to be 0.5 yr^{-1} for all ages in all analyses (Parrish and MacCall 1978).

Data

The assessment model uses an annual time step and now incorporates 75 years (1929-2003) of fishery data, including landings (Table 1, Figure 1), age composition (Figure 2), and mean estimates of weight-at-age (Figure 3). Fishery data for the early historical period (1929-1965) were obtained from previously published assessments (Parrish and MacCall 1978; Prager and MacCall 1988). Abundance estimates from the VPA are adjusted by the model to better match trends in the survey data, which includes aerial spotter sightings (Lo et al. 1992; Figure 4), CalCOFI larval data (Figure 5), recreational fishery catch-per-unit-effort information (Figures 6 and 7), triennial shelf survey data (Figure 8), and power plant impingement rates (Figure 9). As in past assessments, component likelihoods for most surveys were weighted equally to a value of 1.0. The power plant impingement index (age-0 mackerel caught in cooling water at San Onofre Nuclear Generating Station) represents a small portion of the coastline and was therefore down-weighted to 0.1. The ADEPT model can also accommodate weighted annual survey observations based on coefficients of variation (CVs) associated with the individual estimates. As per Hill et al. (2003), we calculated CVs for each survey observation and re-scaled them to a median value. Re-scaling CVs to a value of 1.0 had the benefit of maintaining equal weighting among surveys, while down-weighting observations within surveys for poorly-sampled or highly-variable years.

Fishing Mortality in the Terminal Year

The ADEPT model estimate of terminal F largely determines biomass estimates for the most recent years. Terminal F estimates for each age group were calculated using age-specific vulnerability ('selectivity') parameters and a parameter for the overall fishing mortality rate:

$$[1] \quad F_a = V_a \bullet F \, ,$$

where F_a is the fishing mortality rate at age *a* in the terminal year, V_a is the vulnerability for age *a*, and *F* is the fishing mortality rate experienced by fully-recruited age groups (ages with V_a =1). The parameters F_a, V_a, and *F* were estimated after log transformation to improve numerical estimation. Vulnerability parameters in [1] could, in principle, be estimated individually by ADEPT or set manually to any fixed values based on 'prior' information. It is always desirable to estimate selectivities individually, however, data limitations often cause convergence problems making direct estimation impractical. When specified individually (fixed), the best that can be done is to estimate average vulnerability values by preliminary VPA analysis, then fix terminal selectivities to average values.

For this assessment, we enveloped uncertainty in recent biomass estimates using a method consistent with last year's assessment (Hill et al. 2003). We used fixed age-specific parameters based on vulnerabilities averaged for prior years with catch-at-age similar to 2003 (i.e., large proportion of age 0 and 1 fish in the catch; see Figure 2). After an initial model run using fixed values, ADEPT was configured to estimate selectivities of age 0-3 fish individually (ages 4 and $5 were necessarily fully-selected, i.e., V_a =1 for all model runs). The model converged, however, the parameter for age 2 fish was the only one estimated with any degree of certainty (CV=27%). Model estimates for age 0, 1, and 3 fish were similar to initial values from the default method, but CVs for the estimates were extremely high. Thus, we used fixed values for 0, 1, and 3 year-old fish. Selectivities for age 0 fish are typically low (<0.2), and age 3 fish are moderately vulnerable to the fishery (roughly, 0.4-0.8).

A major area of uncertainty lies in the vulnerability of age-1 mackerel to the fishery. Age-1 vulnerability in the terminal year has the greatest potential impact on biomass calculations for recent years. In other words, a high proportion of age 1 fish in the 2003 catch may be interpreted in two ways: assumed lower vulnerability equates to relatively higher abundance; or assumed higher vulnerability results in relatively lower abundance. Prior model estimates of age-1 vulnerability range from low (~0.2) to high (1.0), with no consistent pattern over the past fifteen years. For the final model run, we developed a broad range of 'states of nature' by calculating the frequency of occurrence of vulnerabilities for four general vulnerability categories (V_a=0.2, 0.4, 0.6, and 0.8) and subsequently, calculated an average vulnerability within each category. Ultimately, four model runs were conducted based on the age-1 vulnerabilities above and finally, these model outputs were used to derive a weighted estimate of important management-related stock parameters (e.g., biomass and recruits). A summary of final V_a parameters follows:

Age	Vulnerability Parameter (V_a)	Source
0	0.066	fixed average based on catch-at-age
1	0.209, 0.408, 0.602, 0.990	four values used to calculate weighted average
2	0.035	model estimated (CV=27%)
3	0.722	fixed average based on catch-at-age
4 and $5	1.000	fixed at 1

Biomass Projection for July 2004

Biomass was estimated through the beginning of 2003 (calendar year), then a projected estimate of biomass for July 1, 2004 was calculated based on: 1) the number of mackerel estimated to comprise each year class at the beginning of 2003; 2) model estimates of fishing mortality during 2003; 3) assumptions for natural mortality (M=0.5) and F through the first half of 2004; and 4) mean weight-at-age for 2003. Weight-at-age data were used to convert numbers of fish to biomass for each age, which was summed across ages to obtain total ($1 year-old fish) biomass.

RESULTS and DISCUSSION

The ADEPT model recalculates biomass and recruitment for all years in the 75-year time series. Differences in biomass estimates among assessment years can be caused by changes in landings, shifts in fishery age compositions, trends in fishery-independent surveys, and assumptions regarding terminal year fishing vulnerability. As is true for all age-structured population models, abundance-at-age estimates are the least certain for the most recent years when the youngest year classes have not yet become fully vulnerable to, or utilized by, the fishery. Compounding this uncertainty is the general lack of fishery or survey data for Pacific mackerel outside the Southern California Bight and the lack of fishery-independent information on recruitment. Catch-at-age and weight-at-age data are not yet available from the Ensenada fishery, which is comparable in volume to California's commercial fishery.

Biomass Trend

Pacific mackerel biomass peaked in 1982 at approximately 1.39 million mt, declining steadily to a low of 10,438 mt in 2001 (Table 2, Figure 13). The peak biomass observed twenty years ago was primarily built by exceptional year classes in the late 1970s and early 1980s (Table 2, Figure 10). These recruitment pulses occurred after a decade of extremely low biomass from the mid-1960s to mid-1970s (Figure 13). The decline in biomass since 1982 has resulted from a steady decline in year class strength (Figure 10) and relatively low reproductive success (recruits per spawning stock biomass; Figures 11 and 12) since that time. Model estimates of 2001 and 2003 year class abundance are slightly higher than for the previous few years and recent reproductive success (recruits per spawning stock biomass) is more optimistic relative to the past 18 years.

The recent trend in $1year-old biomass for the current assessment was similar to that estimated in the 2003 stock assessment (Hill et al. 2003). A precipitous decline in biomass was observed from 1997 to 2001. This decrease is attributed to relatively weak year classes in 1998 to 2000 (Figure 10), combined with high fishing mortality during the 1998 fishery (i.e., keeping in mind that environmental conditions are also believed to strongly influence abundance associated with coastal pelagic stocks in general). The 1998 fishery was the second largest on record (71,355 mt), with the majority (50,726 mt) of the total harvest being landed in Ensenada, Mexico (Table 1, Figure 1). Despite the lower overall estimates of biomass compared with Hill et al (2003), the current time series indicates a stabilization in biomass in the past two years (Figure 13). This may be attributed to what appears to be a relatively strong 2001 year class that contributes substantially to the exploitable biomass. Finally, this stabilization should be interpreted in the context of the historical estimated abundance levels and thus, the population remains at relatively low levels compared with that realized during the 1980s and early 1990s.

Biomass Projection

The July 1, 2004 biomass projection, used to calculate the 2004-2005 HG, was based on ADEPT outputs and certain assumptions about recruitment and fishing mortality during the first half of 2004. Estimates of year class strength (age-0 abundance) for the terminal year (2003) are included in the forecast. Various approaches may be used to address uncertainty in model estimates of age-0 abundance: 1) use a model-derived estimate; 2) use an average of model-derived estimates; or 3) rely strictly on a stock-recruit relationship. Decisions concerning the best approach necessarily depend on assumptions regarding the accuracy of the hypothesized stock-recruit relationship and in particular, the existence of compensatory responses by the stock, i.e., relatively speaking, increased recruitment at low spawning biomass levels.

Reliance on the stock-recruit relationship seems reasonable when model estimates are considerably higher or lower than recently observed values and when no ancillary information exists to suggest that recruitment is atypically high (e.g., year class failure or a compensatory increase in juvenile production and/or survival). The model estimate of age-0 abundance for January 2003 was 310 million fish, well within the range of recruitments observed for the past eight years. Some evidence exists that suggests relatively strong year classes occurred within the past several years. The fishery contained some of the highest proportions of age-0 fish in recent history (e.g., 45% in 2003; Figure 2). The 2000 year class comprised the largest proportion (63%) of the 2002 catch. Length data from recreational angler surveys indicated increased catches of young mackerel by 'shore mode' anglers in 2000 and 2001. Based on the above evidence for stronger year classes, we applied the model estimate of 2003 age-0 abundance in the forecast. The projected estimate of July 1, 2004 population biomass ($1 year-old fish) is approximately 81,383 mt.

HARVEST GUIDELINE RECOMMENDATION FOR 2003-2004

In Amendment 8 to the CPS FMP (PFMC 1998), the recommended maximum sustainable yield control rule for Pacific mackerel was:

HARVEST = (BIOMASS-CUTOFF) x FRACTION x STOCK DISTRIBUTION ,

where HARVEST is the U.S. HG, CUTOFF (18,200 mt) is the lowest level of estimated biomass at which harvest is allowed, FRACTION (30%) is the fraction of biomass above CUTOFF that can be taken by fisheries, and STOCK DISTRIBUTION (70%) is the average fraction of total BIOMASS in U.S. waters. CUTOFF and FRACTION values applied in the Council's harvest policy for mackerel are based on analyses published by MacCall et al. (1985). BIOMASS (81,383 mt) is the estimated biomass of fish age 1 and older for the whole stock as of July 1, 2004. Based on this formula, the 2004-2005 season HG would be 13,268 mt (Table 3, Figure 14). The recommended HG is 2,616 mt higher (+25%) than the 2003-2004 HG, and comparable to the average yield (~12,000 mt) realized by the fishery since the 1992-1993 season (Table 3).

ACKNOWLEDGMENTS

This annual stock assessment depends in large part on the diligent efforts of many colleagues and the timely receipt of their data products. Landings data from the Ensenada fishery were kindly provided by Dr. Celia Eva Cotero of INP-CRIP, Ensenada, Mexico. Port samples and age data were provided by CDFG Marine Region personnel in Los Alamitos and Monterey, with special thanks to Leeanne Laughlin, Valerie Taylor, Kelly O'Reilly, Travis Tanaka, Dianna Porzio, Tom Mason, Sonia Torres, Melissa Nugent for long dockside and laboratory hours. Wendy Dunlap (CDFG, Los Alamitos) supplied logbook data from California's CPFV logbook program. Ron Dotson, Amy Hays, and Sue Manion (NMFS, La Jolla) provided aerial spotter logbook data. Susan Jacobson (NMFS, La Jolla) extracted CalCOFI larval data. Numerous staff from SIO, NMFS, and CDFG assisted in the ongoing collection and identification of CalCOFI ichthyoplankton samples. Mark Wilkins (NMFS, Alaska Fishery Science Center, Seattle, WA) provided swept area estimates from the triennial trawl survey. Kevin Herbinson (Southern California Edison, Rosemead, CA) provided data on mackerel impingement at San Onofre Nuclear Generating Station.

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Table 1. Commercial and recreational landings (metric tons) of Pacific mackerel in California and northern Baja California (Ensenada, Mexico), for calendar years 1929 to 2003. See Figure 1.

Year	CA Com.	CA Rec.	MX Com.	TOTAL	Year	CA Com.	CA Rec.	MX Com.	TOTAL
1929	26,297	134	0	26,431	1966	2,100	492	5,290	7,882
1930	7,498	134	0	7,633	1967	529	260	948	1,738
1931	6,466	134	0	6,600	1968	1,421	189	107	1,718
1932	5,658	134	0	5,792	1969	1,070	288	201	1,559
1933	31,576	134	0	31,711	1970	282	311	0	594
1934	51,641	134	0	51,775	1971	71	538	0	609
1935	66,418	136	0	66,554	1972	49	590	0	639
1936	45,605	43	0	45,648	1973	25	478	0	503
1937	27,641	85	0	27,725	1974	61	246	0	307
1938	36,218	119	0	36,337	1975	131	312	0	443
1939	36,700	234	0	36,934	1976	298	123	0	421
1940	54,660	196	0	54,856	1977	9,220	1,163	0	10,383
1941	35,456	112	0	35,568	1978	21,520	2,256	0	23,776
1942	23,838	111	0	23,949	1979	35,823	3,053	0	38,876
1943	34,117	111	0	34,228	1980	38,188	2,754	0	40,942
1944	37,946	111	0	38,057	1981	42,450	1,394	0	43,844
1945	24,366	111	0	24,477	1982	35,019	1,667	0	36,686
1946	24,437	111	851	25,400	1983	35,454	1,469	135	37,058
1947	21,082	345	1,262	22,689	1984	45,572	1,445	128	47,144
1948	17,865	479	515	18,859	1985	40,514	1,077	2,581	44,172
1949	22,576	225	1,352	24,153	1986	46,557	1,003	4,882	52,441
1950	14,810	141	2,029	16,980	1987	41,212	1,271	2,081	44,565
1951	15,204	99	1,320	16,623	1988	43,991	800	4,883	49,674
1952	9,346	148	1,052	10,547	1989	38,637	611	13,383	52,631
1953	3,403	118	1,177	4,698	1990	39,850	1,126	35,757	76,732
1954	11,518	701	5,681	17,899	1991	32,162	1,190	17,445	50,798
1955	10,573	339	9,798	20,710	1992	19,699	779	24,338	44,815
1956	22,686	258	10,725	33,668	1993	12,680	624	7,739	21,043
1957	28,143	364	2,034	30,541	1994	10,043	947	13,319	24,308
1958	12,541	328	449	13,317	1995	8,667	1,026	4,821	14,514
1959	17,056	213	495	17,765	1996	10,287	694	5,604	16,584
1960	16,696	191	2,981	19,868	1997	20,615	967	12,477	34,059
1961	20,008	274	5,964	26,246	1998	20,073	449	50,726	71,248
1962	22,035	280	3,231	25,547	1999	9,527	197	10,168	19,892
1963	18,254	352	7,966	26,571	2000	23,206	250	7,182	30,637
1964	12,169	243	8,618	21,030	2001	7,785	561	4,078	12,424
1965	3,198	365	7,615	11,177	2002	4,536	279	7,963	12,778
					2003	5,185	341	2,815	8,341

Figure 1. Pacific mackerel landings by fishery for calendar years 1929-2003 (see Table 1).

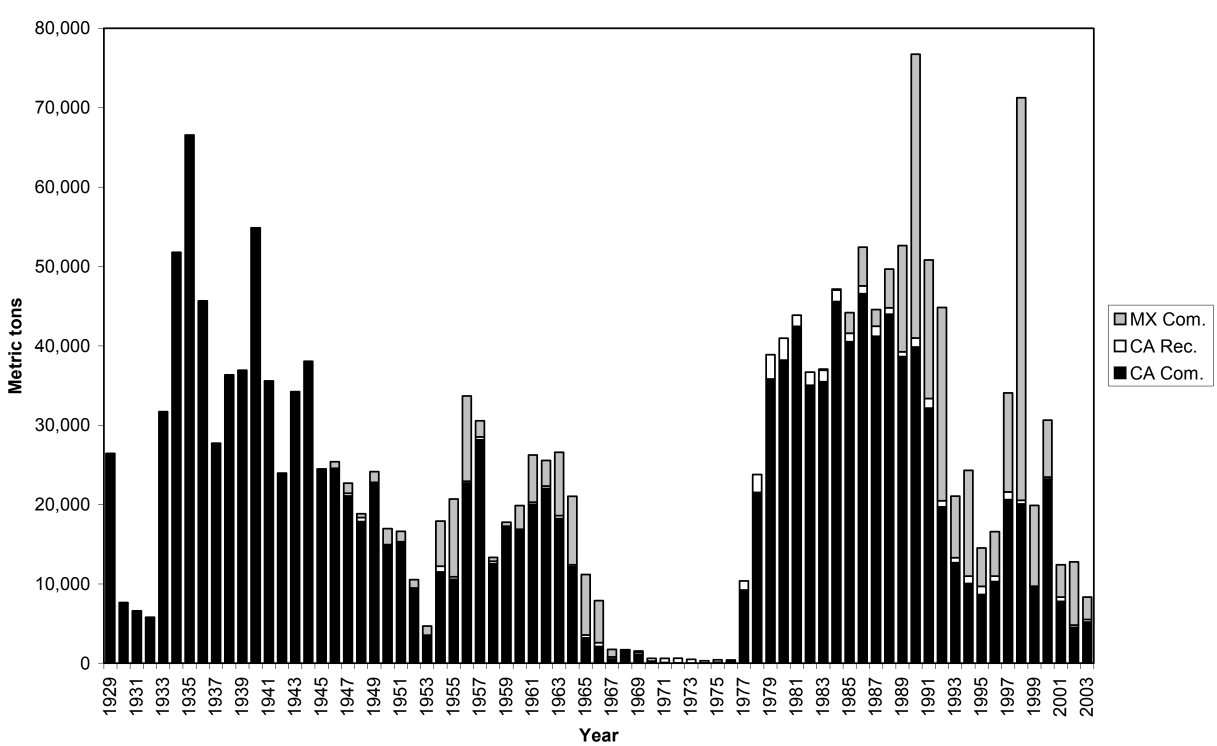

Figure 2. Proportional catch-at-age for California's commercial mackerel fishery, 1984-2003. The assessment model includes data from 1929-2003.

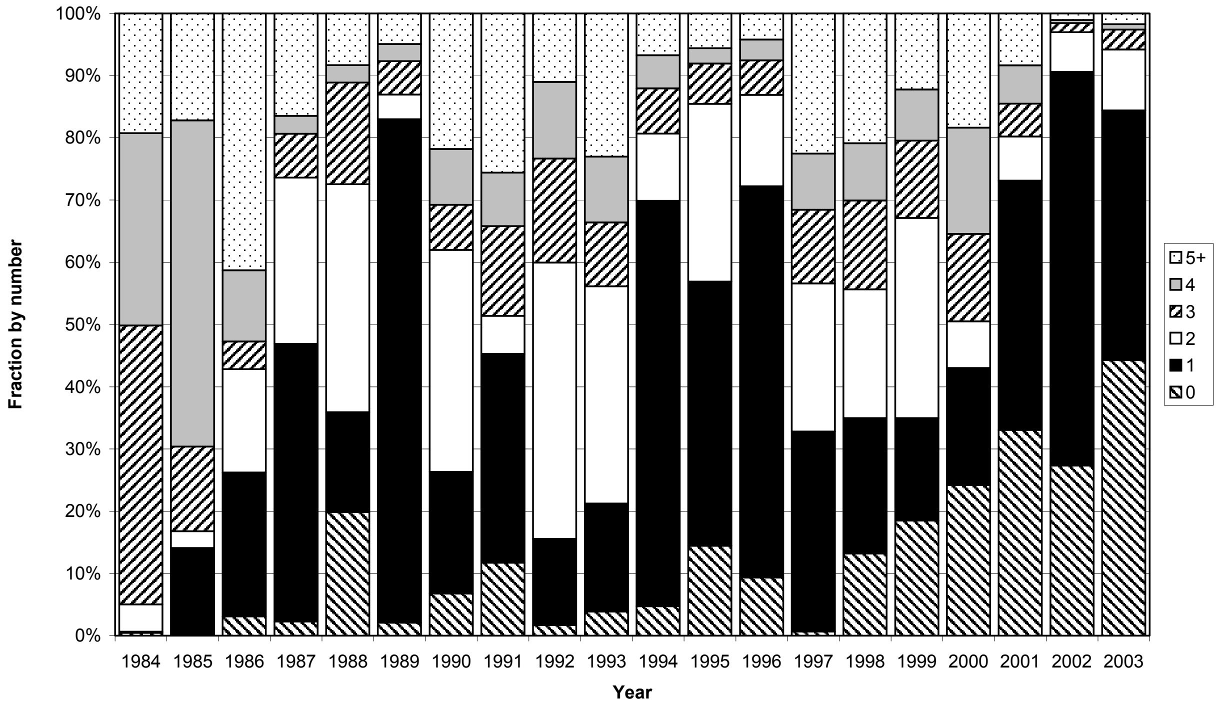

Figure 3. Weight-at-age of Pacific mackerel from California's commercial fishery, 1984-2003. The assessment model includes data from 1929-2003.

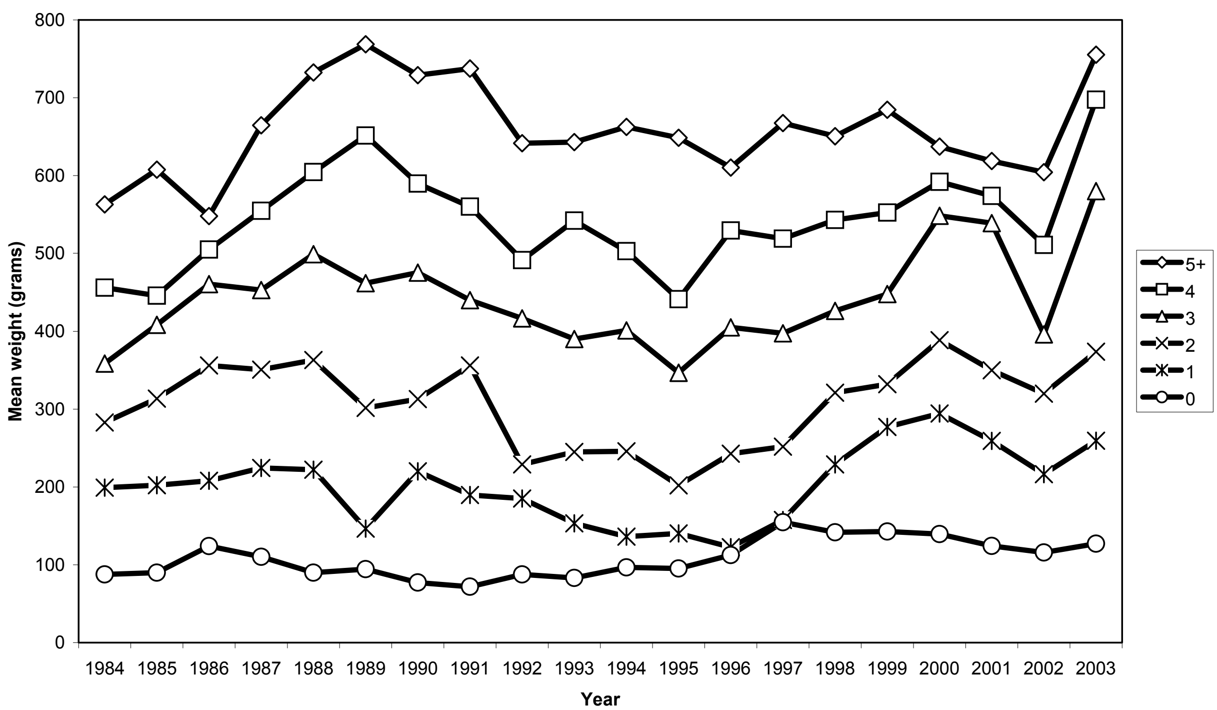

Figure 4. Aerial spotter index of relative abundance.

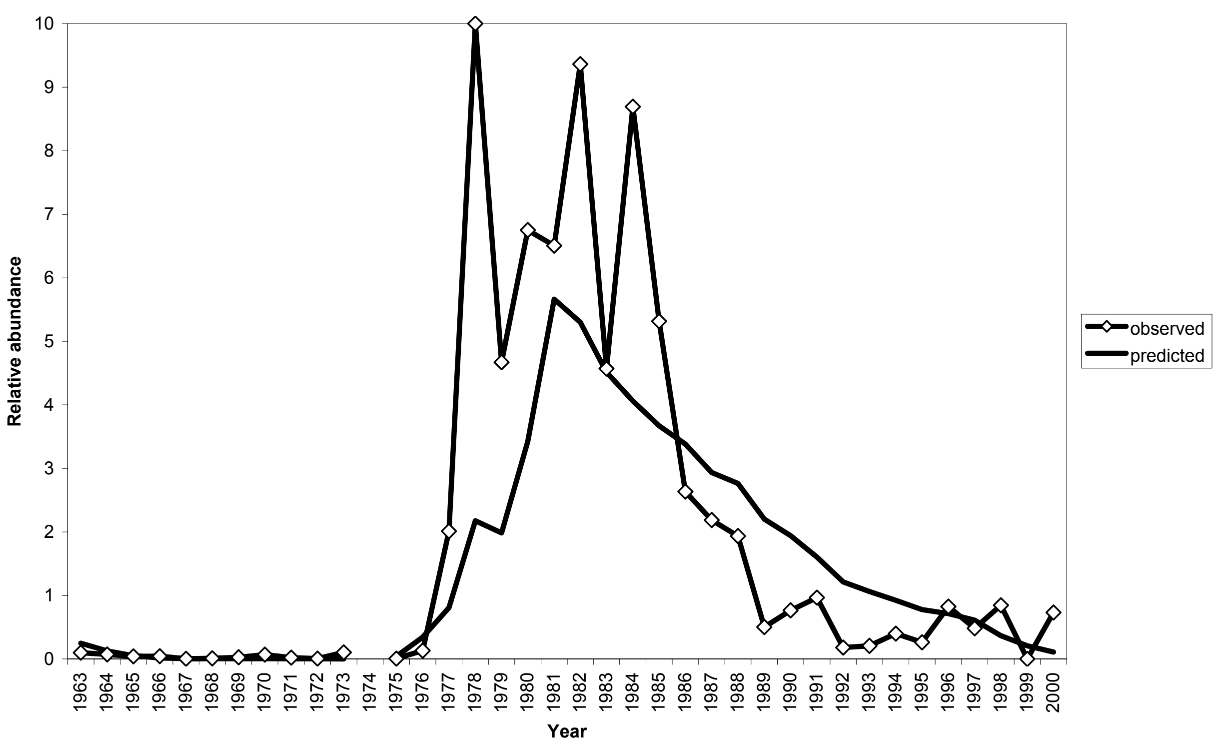

Figure 5. CalCOFI Index - proportion bongo tows positive for Pacific mackerel larvae.

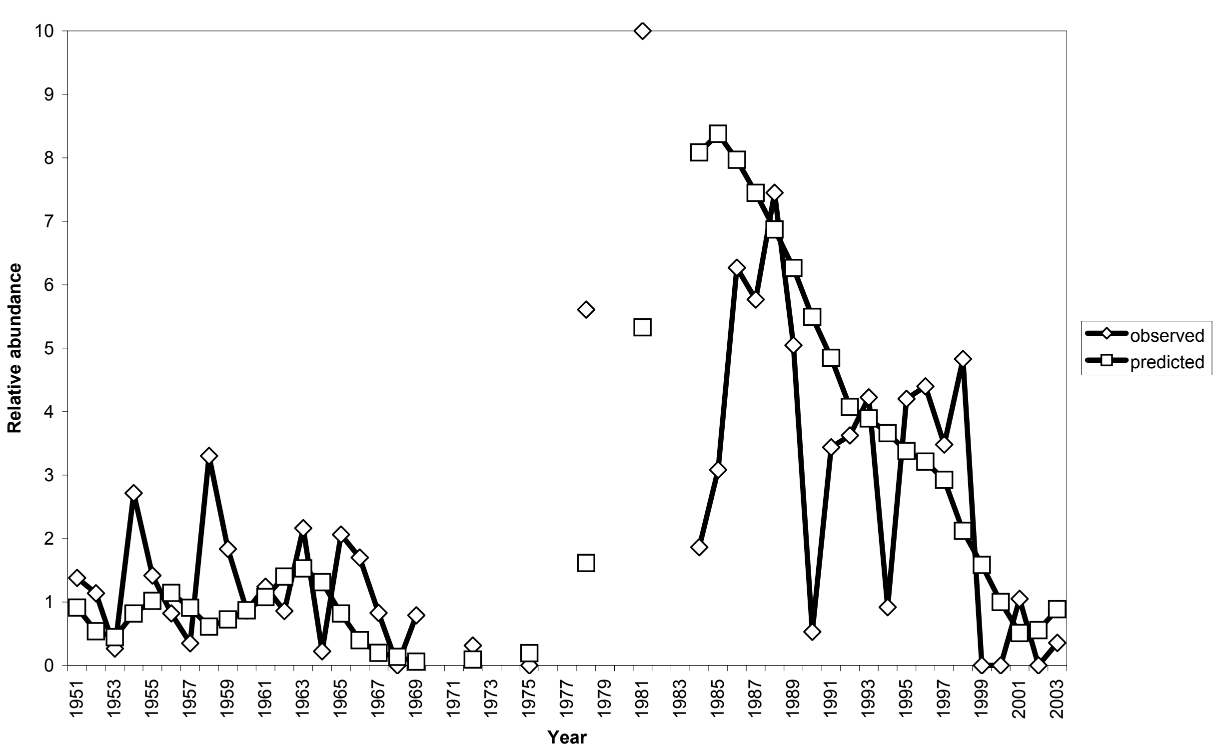

Figure 6. Southern California CPFV CPUE Index.

Figure 7. Northern California CPFV CPUE Index.

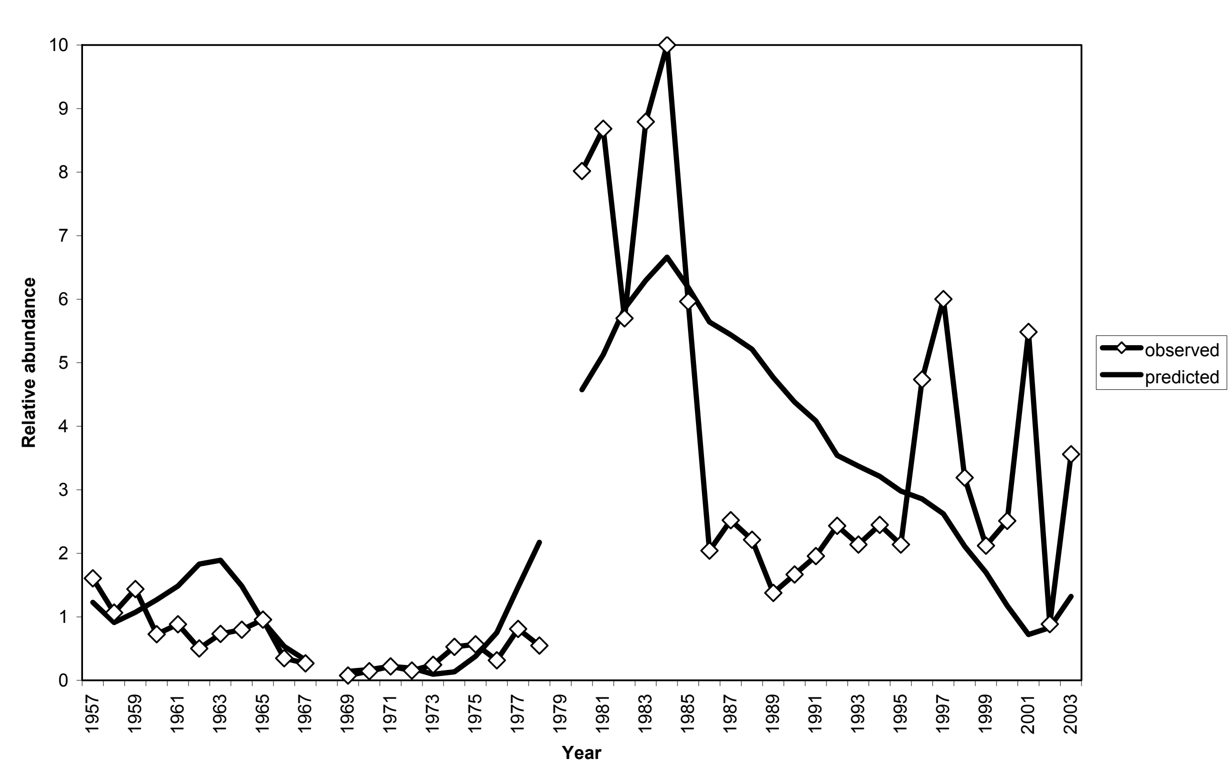

Figure 8. Relative abundance of Pacific mackerel in the trienniel shelf survey, Pt. Conception to the U.S.-Canada border.

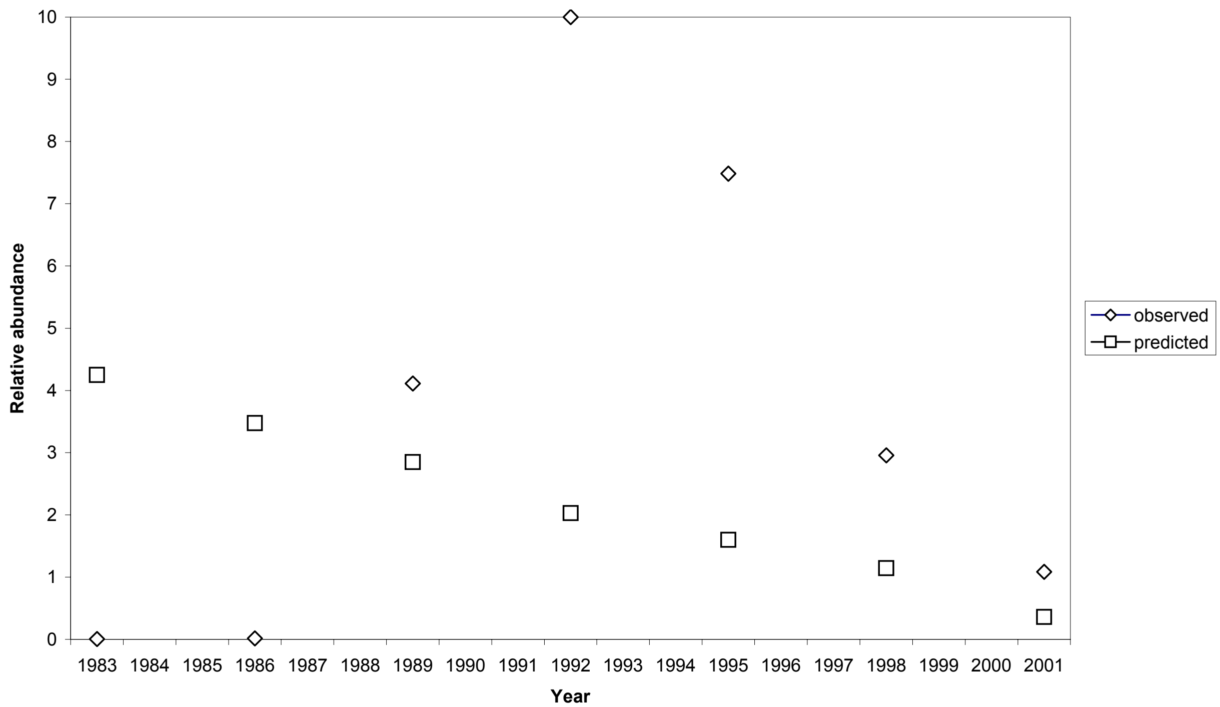

Figure 9. Pacific mackerel impingement at San Onofre Nuclear Generating Station. Index is downweighted to lambda=0.1.

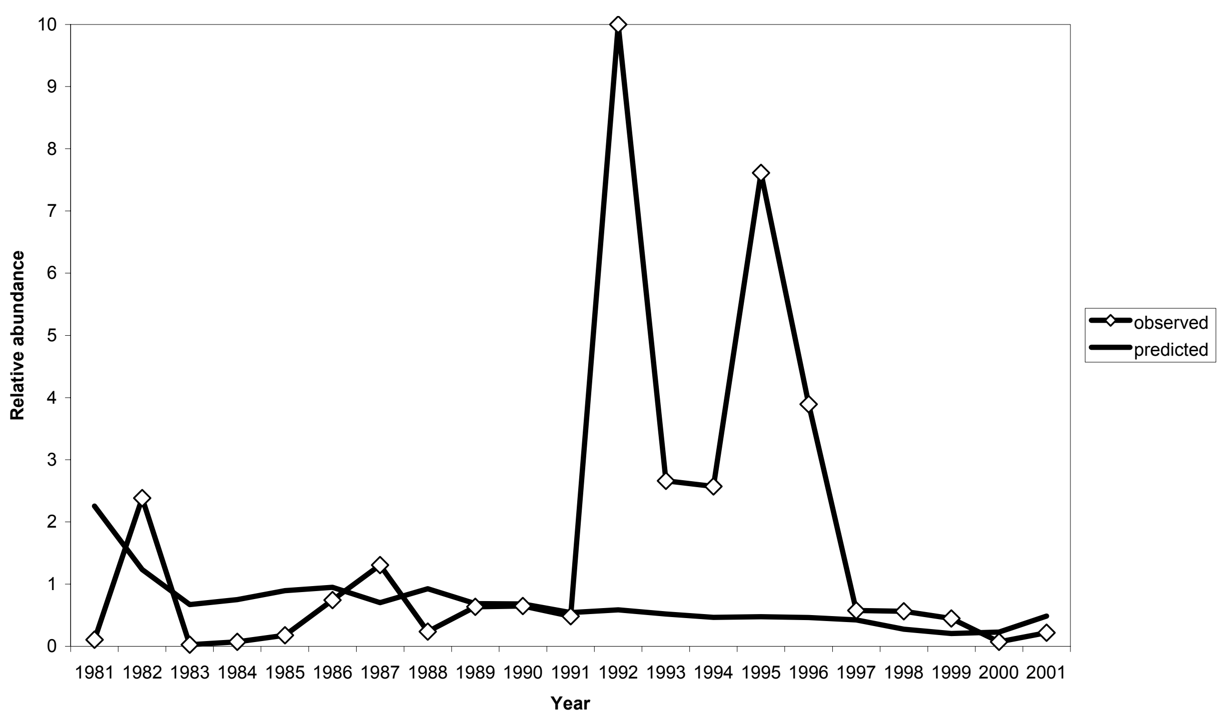

Figure 10. Year class abundance (millions), January 1.

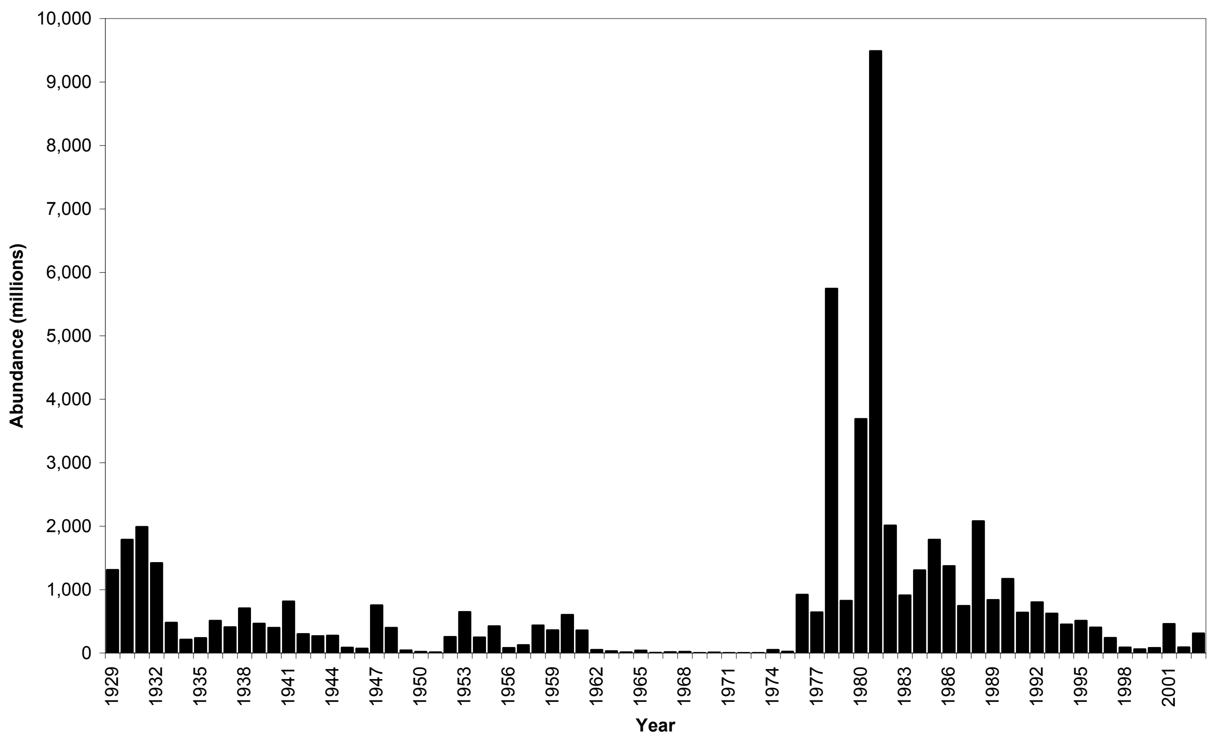

Figure 11. Relative reproductive success of Pacific mackerel, 1930-2003.

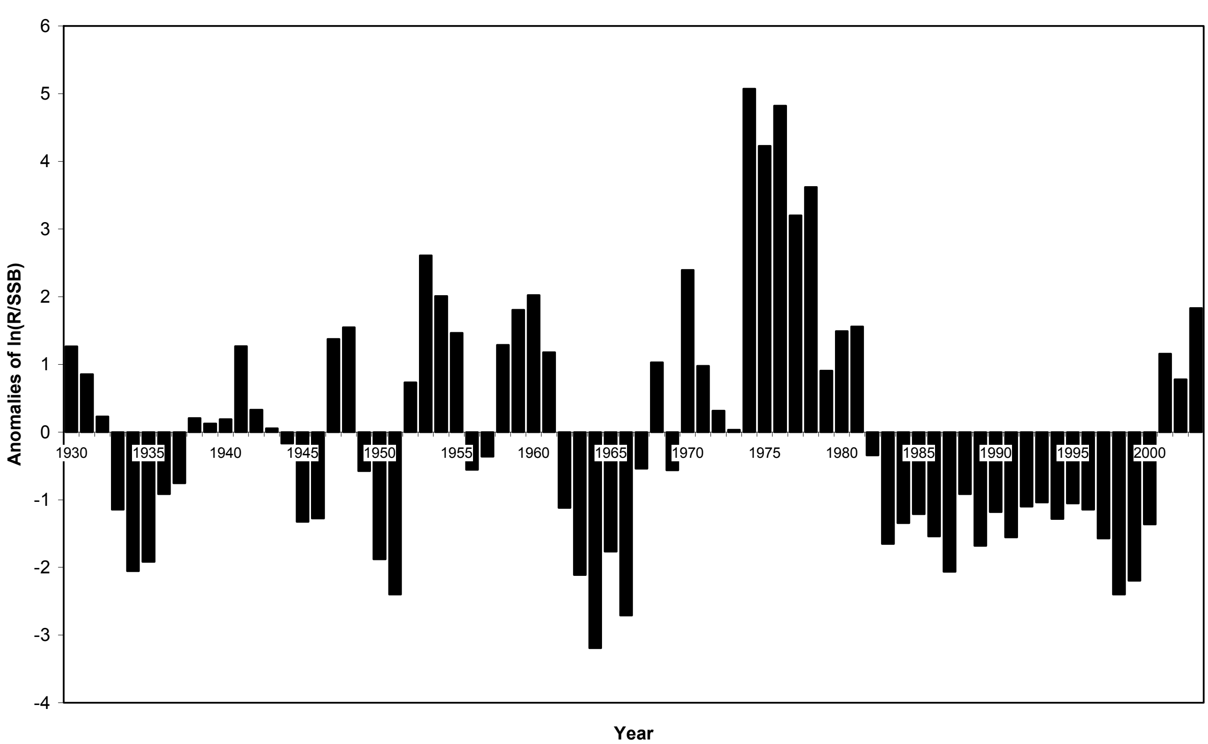

Figure 12. Recruitment Success and Spawning Stock Biomass, 1929/30 to 2002/03.

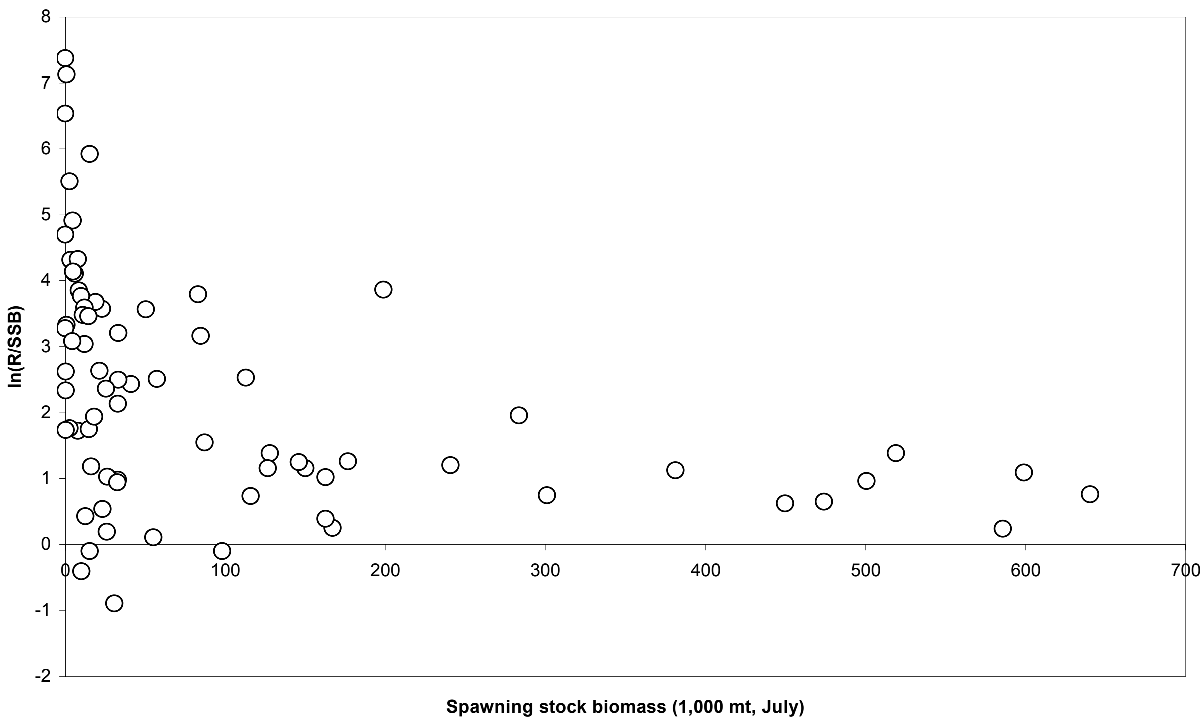

Table 2. Historical July 1 estimates of Pacific mackerel biomass (age 1+, metric tons) and recruitment (age 0, number $1x10^6$) estimated using the ADEPT model. See also Figures 10 and 13.

Year	Age 1+ Biomass (metric tons)	Recruits (millions)	Year	Age 1+ Biomass (metric tons)	Recruits (millions)
1929	155,877	1,020	1967	1,306	6
1930	223,002	1,392	1968	832	12
1931	296,364	1,551	1969	683	2
1932	365,192	1,106	1970	613	6
1933	350,593	373	1971	921	1
1934	289,571	167	1972	433	1
1935	192,391	186	1973	142	1
1936	127,708	399	1974	108	41
1937	114,713	319	1975	9,296	18
1938	105,562	549	1976	13,023	716
1939	116,868	362	1977	146,312	488
1940	91,175	311	1978	160,097	4,474
1941	86,415	635	1979	519,192	641
1942	114,205	233	1980	686,114	2,874
1943	105,781	210	1981	799,251	7,390
1944	84,277	216	1982	1,397,941	1,565
1945	65,374	68	1983	1,257,894	708
1946	41,075	57	1984	1,091,202	1,018
1947	20,862	582	1985	942,444	1,391
1948	57,031	310	1986	851,638	1,066
1949	60,783	35	1987	789,392	578
1950	42,490	15	1988	659,403	1,606
1951	21,921	10	1989	578,228	651
1952	8,133	198	1990	494,960	906
1953	26,276	495	1991	431,022	489
1954	61,752	192	1992	298,738	623
1955	55,043	326	1993	268,740	485
1956	62,478	66	1994	234,638	350
1957	32,664	97	1995	188,211	392
1958	21,300	330	1996	172,344	310
1959	43,937	280	1997	148,508	187
1960	51,512	467	1998	98,564	56
1961	80,677	265	1999	53,798	43
1962	96,241	41	2000	23,888	56
1963	69,787	24	2001	10,438	351
1964	35,922	10	2002	43,881	64
1965	12,602	25	2003	46,121	233
1966	4,198	3	**2004**	**81,383**	**---**

Figure 13. Pacific mackerel biomass estimates and projection, Ages 1+, July 1.

Table 3. Commercial landings (California directed fishery) and quotas (92/93 to 98/99) or harvest guidelines (99/00 to present) for Pacific mackerel. See also Figure 14.

Season	Quota/HG	Landings
92/93	34,010	18,307
93/94	23,147	10,793
94/95	14,706	9,372
95/96	9,798	7,615
96/97	8,709	9,788
97/98	22,045	23,413
98/99	30,572	19,578
99/00	42,819	6,732
00/01	20,740	20,937
01/02	13,837	8,436
02/03	12,535	3,541
03/04*	10,652	5,735
04/05**	**13,268**	---

* projected 03/04 landings.
** proposed harvest guideline for 2004/2005.

Figure 14. Pacific mackerel quotas (CA, pre-99/00) and harvest guidelines (PFMC, 99/00 onward), and resultant landings for each management season (see Table 3). The proposed HG for 2004/05 is 13,268.